[redacted]

NACA

RESEARCH MEMORANDUM

SOME RECENT EXPERIMENTAL DATA ON THREE-DIMENSIONAL OSCILLATING AIR FORCES

By Sumner A. Leadbetter and Sherman A. Clevenson

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

June 27, 1955

[redacted]

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

SOME RECENT EXPERIMENTAL DATA ON THREE-DIMENSIONAL OSCILLATING AIR FORCES

By Summer A. Leadbetter and Sherman A. Clevenson

SUMMARY

The status of oscillating air forces is indicated. Forces, moments, and their respective phase angles are shown for a 45° swept wing of aspect ratio 2 and for two bodies of revolution, one a streamline body and the other, an open tube. For comparison, derivatives based on available analyses were shown for these three configurations. Damping-moment derivatives are given for a tank located over the end of a wing and indicates the effect of the presence of a fin on the tank. In-phase and damping-moment derivatives are presented for a wing-tank combination with the fin location either inboard or outboard. It is indicated that the inboard location increases the aerodynamic damping in the torsional mode and an outboard position would tend to increase the divergent speed.

INTRODUCTION

The accuracy of predicting the limiting flutter speeds of aircraft depends on how well the component forces which appear in a flutter analysis are known, that is, how well the aerodynamic, elastic, and inertia forces are known. Regarding knowledge of the aerodynamic forces of flutter, theory has contributed much, but many uncertainties still exist. It becomes necessary to rely on experiment to check the various theories as well as to handle cases which are too complex for theoretical analysis. Considerable work on some of the analytical aspects of the oscillating air-force problem is currently being done by Harry L. Runyan and Donald S. Woolston of the Langley Aeronautical Laboratory. It is the purpose of this paper to indicate the status of available experimental data on oscillating air forces and to present some current results of experiments in the Langley 2- by 4-foot flutter research tunnel on wings and bodies. Some of the current experimental results are compared with the results of analyses. The configurations discussed are swept wings, bodies at the end of struts, and wings with tip tanks with and without fins.

[redacted]

SYMBOLS

c chord of wing in stream direction, ft

k reduced-frequency parameter, $\frac{c\omega}{2V}$

L length of body, ft

M Mach number

q dynamic pressure, lb/sq ft

S plan-form area, sq ft

V wind velocity, ft/sec

α angular displacement, radians

ϕ_L phase angle by which the lift vector leads the angular displacement, deg

ϕ_M phase angle by which the moment vector leads the angular displacement, deg

ω circular frequency of oscillation, radians/sec

$c/2$, $L/2$ subscripts referring to the midchord and midlength positions

RESULTS AND DISCUSSION

Status of Experimental Oscillating Air Forces

Before presenting the three-dimensional oscillating air-force derivatives for the aforementioned configurations, it is appropriate to illustrate briefly the status of experimental oscillating air forces, indicating in what regions experimental data are available. Figure 1 shows the ranges in which data are available for five configurations. The ordinates of each figure is the conventional flutter parameter k which is the oscillation frequency times a reference chord divided by twice the velocity. The abscissa is Mach number. The black areas indicate regions for which oscillating air-force data are available and may be found in references 1 to 17, whereas the cross-hatched areas indicate regions in which data have been obtained and are available in this paper. Data are available for rectangular wings of low aspect ratio, swept wings, delta wings, wing tank over the end of a wing of aspect ratio 2, and two bodies of revolution - one an open circular tube and the other a streamline body, each at the end of a small round tapered strut. All models were oscillated in pitch about an axis of rotation as indicated. Some data are also available for other rigid body modes such as vertical translation and rolling motion and for some flexible modes in limited areas of the black regions. The following discussion and presentation of oscillating aerodynamic derivatives will concern some recent representative experimental data on a 45° swept wing oscillating about its root-midchord axis, two bodies of revolution - an open tube and a streamlined body - at the ends of short struts, and a wing-tip-tank combination with and without fins.

45° Swept Wing of Aspect Ratio 2

The oscillating air-force and moment derivatives for a 45° swept wing of aspect ratio 2 are shown in the figure 2. The ordinates are ϕ_L, and ϕ_M, the angles by which the lift and moment lead the angular position, and the lift and moment derivatives, where q is the dynamic pressure, S is the plan-form area, α is angular displacement, and $c/2$ is the half chord measured in the stream direction. The sketch in the upper right-hand corner indicates three dimensionally how a half-wing was mounted on a plate and oscillates with the plate. A small gap separates the plate from the tunnel wall. The solid symbols are for the moment data and the open symbols are for lift data. For comparison, experimental data obtained from integrated pressure distribution at the Massachusetts Institute of Technology (ref. 8) are shown as squares. All moment data are referred to the 50-percent root-chord station. As a matter of interest, theory for a two-dimensional 45° swept wing (ref. 2) is included and shown as the solid and dashed curves - the solid curves for the lift derivative and lift phase angle, the dashed curves for the moment derivative and moment phase angle. It may be seen that the theory for the lift and moment phase angles agree rather well with the experimental data. However, theory for the lift derivative underestimates the experimentally determined lift derivatives, and theory for the moment derivatives overestimates the experimentally determined values. Thus, as might be expected, two-dimensional theory is inadequate for predicting the oscillatory lift and moment derivatives on a 45° swept wing of aspect ratio 2.

Bodies of Revolution

The use of large external stores attached to wings raises the question as to the oscillating air forces on these bodies. Two bodies of fineness ratio 7 have been oscillated in pitch about their midlengths, and sets of derivatives and phase angles have been determined. The first configuration is a streamlined body supported by a single strut as indicated in figure 3. In the upper right-hand corner is a sketch indicating how the strut is mounted on the end plate. The ordinates are as shown in figure 2: ϕ_L, ϕ_M, and lift or moment derivative. The experimental lift and lift phase angles are indicated by circles and the moments and moment phase angles are indicated by squares. Shown for comparison are the results of an analysis based on slender-body theory presented in reference 5 for a streamlined body. Since this theory is based on potential flow, it should not be expected to predict the results of the experiment. For instance, at $k = 0$ the experimental lift derivative is 0.06π whereas the analyses predicted it to be zero and the corresponding experimental moment derivative was 0.08π compared to the analytical value of over 0.12π. The moment phase angles appear to have some agreement but the analytical lift phase angles differ greatly from those obtained experimentally. This lack of agreement between analysis and experiment is not unexpected considering that the analysis does not account for boundary-layer separation or viscosity effects on the body.

The second body upon which oscillating air forces have been determined was an open tube - similar to a stove pipe - as shown in figure 4. This tube could be considered as a simplified ramjet minus the internal mechanisms. The tube was mounted on the same strut as the streamlined body and has the same ratio of length to maximum diameter and was oscillated at approximately the same frequency. Thus forces on the tube are directly comparable to the measured forces on the streamlined body. It may be noted that for the open tube the lift derivatives are considerably greater and the moment derivatives are slightly greater than for the streamlined body. The lift phase angles are similar and the magnitudes of the moment phase angles are larger for the open tube than for the streamlined body. For comparison with this experimental data, curves of theory were determined from reference 5 for the open tube and are shown as the solid curves. The trends of the theoretical phase angles agree with experimental trends as does the trend of the lift derivatives. The experimental moment derivatives tend to indicate that the moment derivative is independent of k although the theory indicates that the moment should increase with k. Although the preceding data may not be directly applicable to a flutter analysis, they do give some insight as to the oscillating air forces present on bodies by themselves.

Wing With Tip Tank

The last configuration for which data will be presented is a tip tank over the end of a wing of aspect ratio 2. The addition of a fin in the plane of the wing on a tip tank is of interest from a flutter standpoint. Some data have been obtained over a small k range on the damping moment contributed by a tank of fineness ratio 5.7 over the end of a wing of aspect ratio 2 and are presented in figure 5. The sketch in the upper right-hand corner illustrates in plan form the wing with the tip tank attached. In order to find an effect of fin shape, a trapezoidal and a delta fin were used as indicated. The tank was mounted on strain beams such that the forces measured are the forces on the tank alone. The ordinate of the graph is the damping-moment derivative where S is the plan-form area of the tank. The abscissa is the usual flutter parameter k. The circles represent the no-fin condition, the squares the delta fin, and the triangles represent the trapezoidal fin. From a comparison of the square and triangle, it may be seen that the damping-moment derivative on the tank is essentially the same regardless of which fin is used. However, all of these moments are less than the no-fin condition. It may be noted that, although all the magnitudes of the damping derivatives are very small, under 0.06π in this low k range, the addition of a fin in this position decreases the damping moment on the tank for the torsional mode and may be detrimental from a flutter standpoint. A possible explanation of this decrease in damping is that the fin, placed in an outboard position on the tank, is in the upwash of the tip vortex. Thus the presence of the fin on the tank in the upwash reduced the damping contributed by the tank rather than increasing the damping as may have been expected.

Experimental moment derivatives for the wing-tank combination instead of the tank alone are given in figure 6. In addition to the data for the trapezoidal fin in the outboard position, derivatives are presented for the fin in the inboard position, shown dotted in the sketch. The effects of a fin being in the downwash as well as the upwash of the tip vortex will be indicated. The upper graph shows the in-phase moment derivatives as a function of k and the lower graph shows the damping-moment derivatives as a function of k. These derivatives are for the combined moments for the wing and tank together. The S used in these derivatives is the plan-form area of the combination wing and tank, or wing, tank, and fin as the case may be. It may be noted in the lower figure that the damping derivatives for the fin in the outboard position and for the no-fin condition are practically the same, whereas for the fin in the inboard position the damping derivatives are greater. Thus from considerations of damping in the torsional mode, it would be better to have the fin inboard. However, the detrimental effect of the inboard fin is indicated in the upper figure. It is seen that the in-phase moment derivatives for the inboard fin or no-fin condition are about the same. The outboard-fin condition results in a much smaller value of in-phase moment derivative at the lower values of k. It must be remembered that a larger value of in-phase moment results in a lower divergence speed. The lower value of in-phase moment as shown by the fin in the outboard position is beneficial from a viewpoint of divergence in that it would cause the divergence speed to be higher than that which would result from no fin or fin in the inboard position. It may be concluded that the fin located in an inboard position may be of some benefit regarding flutter since it caused an increase in damping in the torsional mode, whereas the fin located in an outboard position would be of benefit regarding divergence.

CONCLUDING REMARKS

This paper deals with the status of oscillating air forces, indicating regions of available data and regions for which data are presented in this paper. Forces, moments, and their respective phase angles were shown for a 45° swept wing of aspect ratio 2 and for two bodies of revolution, one a streamline body and the other, an open tube. For comparison, derivatives based on available analyses were shown for these three configurations. Damping-moment derivatives were given for a tank located over the end of a wing and indicated the effect of the presence of a fin on the tank. In-phase and damping-moment derivatives were presented for a wing-tank combination with the fin location either inboard or outboard. It was indicated that the inboard location increased the aerodynamic damping in the torsional mode and an outboard position would tend to increase the divergent speed.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 20, 1955.

REFERENCES

1. Ashley, H., Zartarian, G., and Neilson, D. O.: Investigation of Certain Unsteady Aerodynamic Effects in Longitudinal Dynamic Stability. USAF Tech. Rep. No. 5986. (Contract No. AF 33(038)-11668, RDO No. R458-414b), Wright Air Dev. Center, U. S. Air Force, M.I.T., Dec. 1951.

2. Barmby, J. G., Cunningham, H. J., and Garrick, I. E.: Study of Effects of Sweep on the Flutter of Cantilever Wings. NACA Rep. 1014, 1951. (Supersedes NACA TN 2121.)

3. Beam, Benjamin H.: The Effects of Oscillation Amplitude and Frequency on the Experimental Damping in Pitch of a Triangular Wing Having an Aspect Ratio of 4. NACA RM A52G07, 1952.

4. Clevenson, Sherman A., Leadbetter, Sumner A., and Tuovila, Weimer J.: Discussion of Three-Dimensional Oscillating Air Forces Based on Wind-Tunnel Measurements. NACA RM L53E18a, 1953.

5. Clevenson, S. A., Widmayer, E., Jr., and Diederich, Franklin W.: An Exploratory Investigation of Some Types of Aeroelastic Instability of Open and Closed Bodies of Revolution Mounted on Slender Struts. NACA TN 3308, 1954. (Supersedes NACA RM L53E07.)

6. Goodman, Alex, and Brewer, Jack D.: Investigation at Low Speeds of the Effect of Aspect Ratio and Sweep on Static and Yawing Stability Derivatives of Untapered Wings. NACA TN 1669, 1948.

7. Henderson, Arthur, Jr.: Investigation at Mach Numbers of 1.62, 1.93, and 2.41 of the Effect of Oscillation Amplitude on the Damping in Pitch of Delta-Wing—Body Combinations. NACA RM L53H25, 1953.

8. Laidlaw, W. R.: Theoretical and Experimental Pressure Distributions on Low Aspect Ratio Wings Oscillating in an Incompressible Flow. Tech. Rep. 51-2 (Contract NOas 52-576-c, Bur. Aero.), Aeroelastic and Structures Res. Lab., M.I.T., Sept. 1954.

9. Leadbetter, Sumner A., and Clevenson, Sherman A.: Some Measurements at Subsonic Speeds of the Aerodynamic Forces and Moments on Two Delta Wings of Aspect Ratios 2 and 4 Oscillating About the Midchord. NACA RM L53J26a, 1953.

10. Mollo-Christensen, Erik L., and Lewis, S. Dean: An Exploratory Investigation of Unsteady Transonic Flow. Part II - Experimental Results. TACP Rep. 6 (Contract No. AF 33(038)-22184), Aero. Eng. Dept., M.I.T., Aug. 1954.

11. Rainey, A. Gerald: Preliminary Study of Some Factors Which Affect the Stall-Flutter Characteristics of Thin Wings. NACA RM L52D08, 1952.

12. Scruton, C., Woodgate, L., and Alexander, A. J.: Measurements of the Aerodynamic Derivatives for an Arrowhead and a Delta Wing of Low Aspect Ratio Describing Pitching and Plunging Oscillations in Incompressible Flow. S. & C. 2810, British N.P.L. (Rep. No. 16,210, A.R.C.), Oct. 1953.

13. Scruton, C., Woodgate, L., and Alexander, A. J.: Measurements of the Aerodynamic Derivatives for a Clipped Delta Wing of Low Aspect Ratio Describing Pitching and Plunging Oscillations in Incompressible Flow. S. & C. 2719, British N.P.L. (Rep. No. 15,499, A.R.C.), Dec. 1952.

14. Tobak, Murray: Damping in Pitch of Low-Aspect-Ratio Wings at Subsonic and Supersonic Speeds. NACA RM A52L04a, 1953.

15. Tobak, Murray, Reese, David E., Jr., and Beam, Benjamin H.: Experimental Damping in Pitch of 45° Triangular Wings. NACA RM A50J26, 1950.

16. Widmayer, Edward, Jr., Clevenson, Sherman A., and Leadbetter, Sumner A.: Some Measurements of Aerodynamic Forces and Moments at Subsonic Speeds on a Rectangular Wing of Aspect Ratio 2 Oscillating About the Midchord. NACA RM L53F19, 1953.

17. Wilson, Leo E.: The Measurement of Nonstationary Airload Distributions on a Straight Flexible Wing Oscillating in a Subsonic Wind Stream. Rep. No. P245C-22 (Contract No. AF 33(616)-176), Southwest Res. Inst., May 1954.

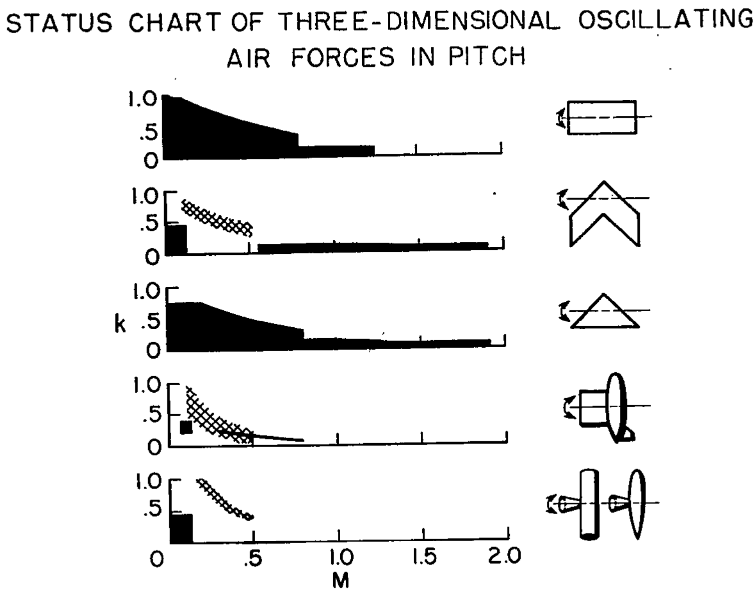

Figure 1

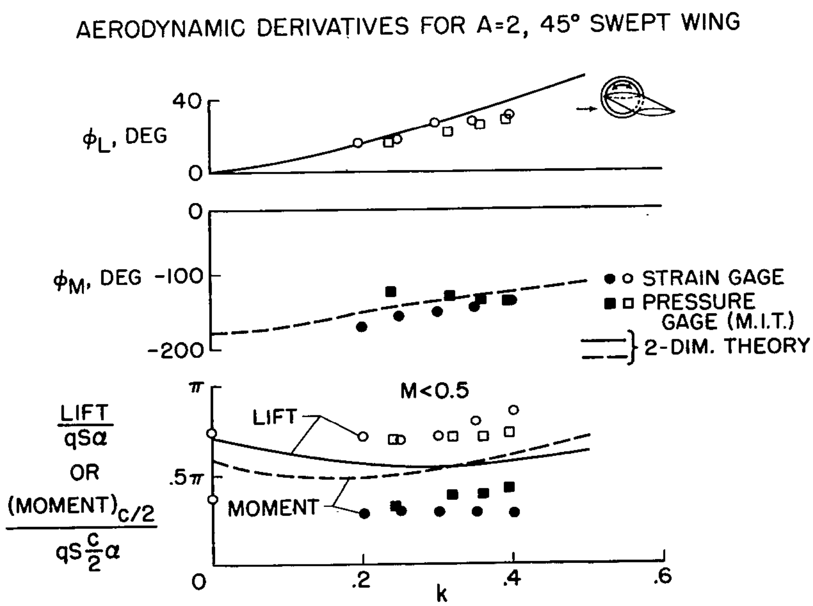

Figure 2

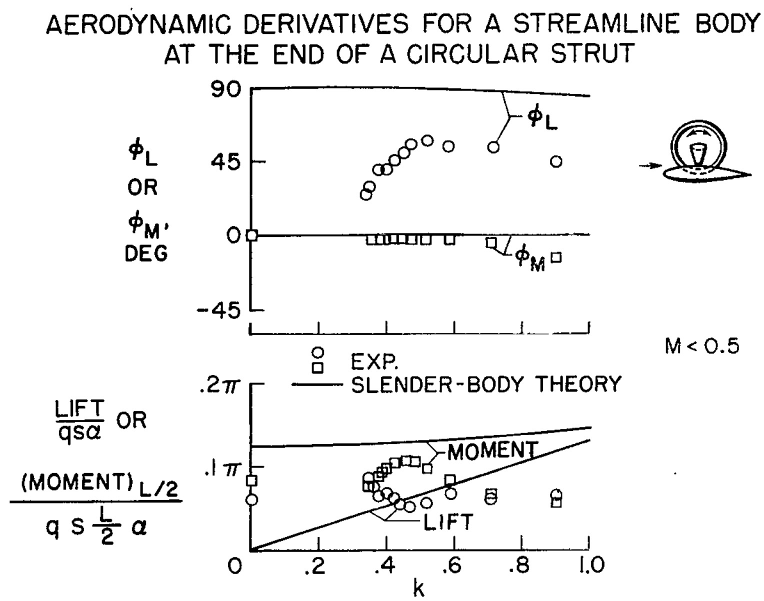

Figure 3

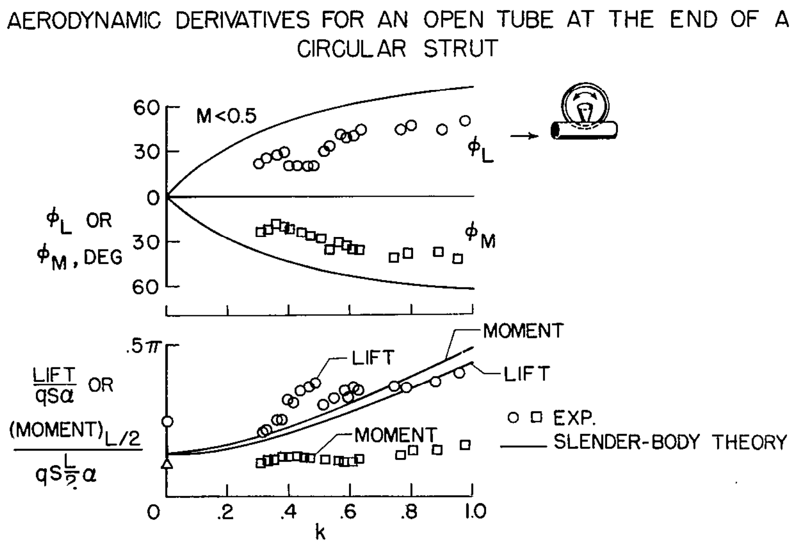

Figure 4

EFFECT OF FIN ON DAMPING-MOMENT DERIVATIVE ON TIP TANK
IN PRESENCE OF WING

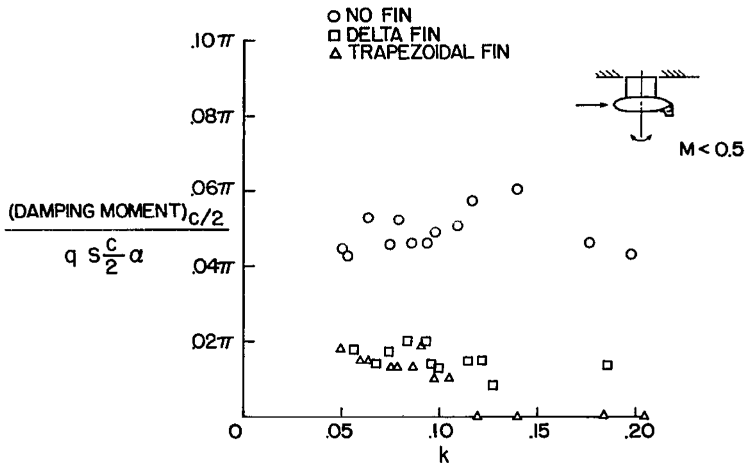

Figure 5

EFFECT OF FIN LOCATION ON MOMENT DERIVATIVES
ON A WING – TANK COMBINATION

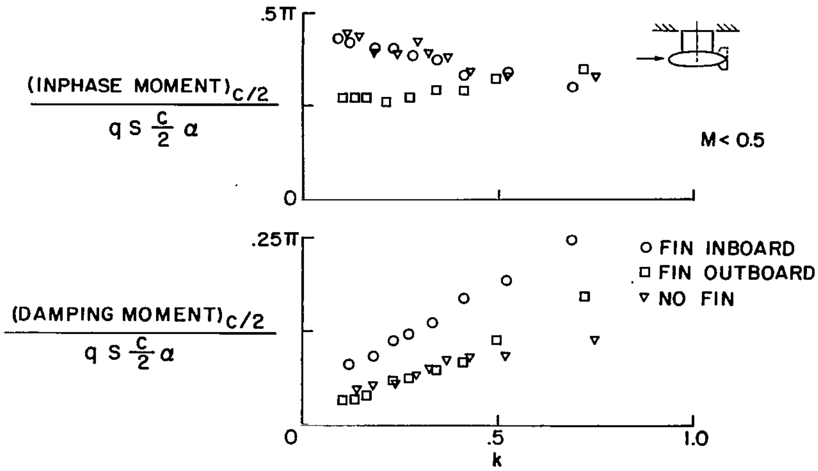

Figure 6

~~CONFIDENTIAL~~